INTEGRATING DISPARATE KNOWLEDGE TO IMPROVE NATURAL RESOURCE MANAGEMENT

C.S. Smith[A,B] *and O.J.H. Bosch*[A,B]
[A] School of Natural and Rural Systems Management, University of Queensland, Gatton, Australia.
[B] Collaborative Research Centre for Tropical Savannas Management

Abstract
Knowledge is a valuable resource in the development of natural resource management (NRM) strategies. However, available knowledge is often under-utilised, particularly that knowledge not created by science. This paper describes some simple processes and tools for unlocking, modeling, combining and using the disparate knowledge held by stakeholder groups in the development of NRM strategies and for adaptive management. These have the potential to improve NRM by utilising a range of existing knowledge in strategy development (planning), by improving the adoption and implementation of those management strategies by local resource managers, and by allowing stakeholders to review that success of their management strategies over time.

Additional Keywords: Knowledge Building, Bayesian Belief Networks, Adaptive Management

The Nature of Knowledge
Only when organizations are able to combine and integrate diverse sources of information, and to take them to a higher level where information becomes knowledge, will they realize the full power of their information ecology (Davenport 1997).

Data, information and knowledge form the base for intelligent natural resource management (NRM). They are what we use to make decisions and guide action. In practice, data, information and knowledge form a continuum. This continuum is represented by the KID (Knowledge, Information, Data) triangle (Figure 1).

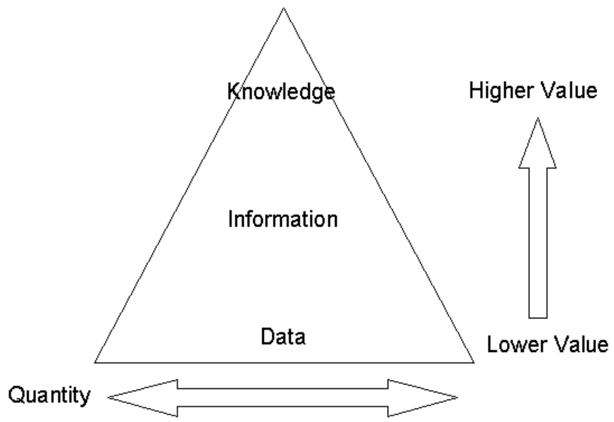


Figure 1. The KID triangle (after Bryceson 2003)

The KID triangle shows the inverse difference between the quantity and value of data, information and knowledge. There are vast amounts of data and information being generated about NRM issues and made available via publications, databases and web sites. However, the amount of knowledge available to decision makers, which is of the highest value in decision-making, is much less. This is due to the nature of knowledge.

Data are measurements or observations and *information* is the product of data analysis and interpretation (such as trends, percentages, correlations). They are easy to capture, organise and store, and therefore are easy to transfer from person to person. *Knowledge* on the other hand is the tacit “Know-What” and “Know-How” stored in the peoples minds. It is derived from synthesis of information, experience, beliefs and intuition. Unlike data and information, it is difficult to capture, organise and store and is difficult to transfer from person to person. Consequently, knowledge relating to particular NRM issues is disparate and diffuse. It is also highly mobile and easily lost.

Knowledge and the Problems for Resource Management

The nature of knowledge presents a problem for NRM in that management strategies may be based on an abundance of scientific data and information, but on partial knowledge. Many sources of knowledge are overlooked when formulating resource management strategies, particularly local knowledge (Mackinson and Nottestad 1998). This has the potential to severely limit NRM strategies because, a) they may not be based on the full range of existing knowledge, or b) they may not be adopted and implemented by local resource managers because they do not incorporate (or agree with) their understanding.

An additional problem is that the knowledge of NRM systems is often very uncertain. Also, environmental, economic and social (including political and institutional) conditions are continuously changing. In practice, this means that it is extremely difficult (sometimes impossible) to predict how successful NRM strategies will be in the long term.

Approaches to Overcome these Problems

The approaches suggested in this paper to overcome these problems, are two fold:

- Developing tools and processes for utilising different sources of knowledge so that NRM strategies can be formulated using a common understanding (among stakeholders) of the resource management system.
- Developing tools and processes to support adaptive management so that NRM strategies can be tested and changed over time as our understanding of the resource management system develops (or circumstances change).

The Knowledge Building (KB) project within the Cooperative Research Centre for Tropical Savannas Management (CRC) is currently conducting research into the development of these processes and tools. The rest of this paper briefly outlines some of these, using examples from a case study on grazing land condition management in the Northern Gulf region of Queensland.

Maintaining land condition is one of the key objectives of the Northern Gulf Resource Management Group (NGRMG). This group is the regional planning body for the Northern Gulf, made up of stakeholder representatives. The dominant land use in the region is extensive cattle grazing on predominately native pastures. Most grazing is on pastoral leases and there is extensive grazing experience held by the leaseholders. In addition, the Queensland Department of Primary Industries (DPI) is developing a grazing land condition assessment system. This system is based on a four classes – A - good condition, B - fair condition, C - poor condition and D - very poor condition. Each class is defined by the content of 3P grasses (Productive, Palatable, Perennial), ground cover, the degree of weed infestation and the degree of woodland thickening (tree density). The CRC is also conducting research into the management of aspects of land condition, such as pasture, weed and tree density management. Hence there is a variety of knowledge about land condition management in the region.

Figure 2 summarises the situation in the Northern Gulf land condition case study. The aim is to build a knowledge base from graziers, the NGRMG, government agencies knowledge (such as DPI, and CRC scientists) so that a common understanding of land condition, what it means, what influences it and how it can be managed can be developed.

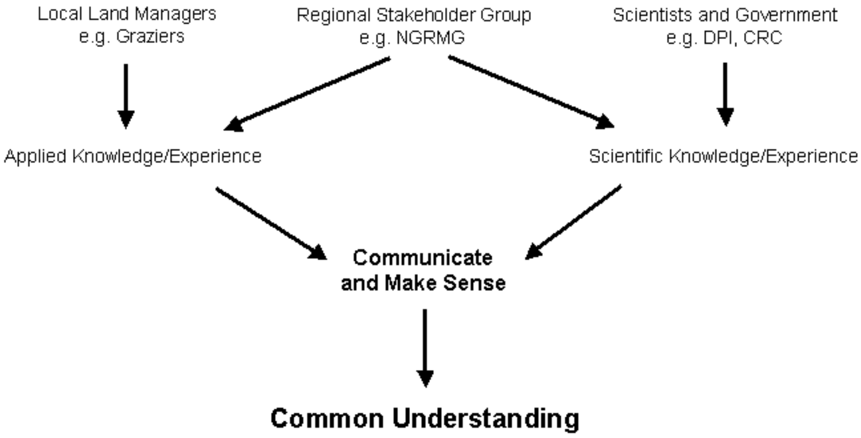


Figure 2. Developing a common understanding of land condition in the Northern Gulf region.

The basic steps in the knowledge building process are:

- Unlocking (eliciting) knowledge from the different stakeholder groups.
- Modelling, explicitly representing and combining that knowledge.
- Making sense of existing knowledge in order to develop a common understanding of the NRM system.
- Building on that knowledge into the future.

These steps are similar to those in the SECI model for knowledge creation (Nonaka and Konno 1998). This model describes how tacit knowledge through a process of **socialisation**, is **externalised** (becomes explicit) and explicit knowledge then **combined** via communication across a group of people, and finally **internalised** by group members as learning (Figure 3).

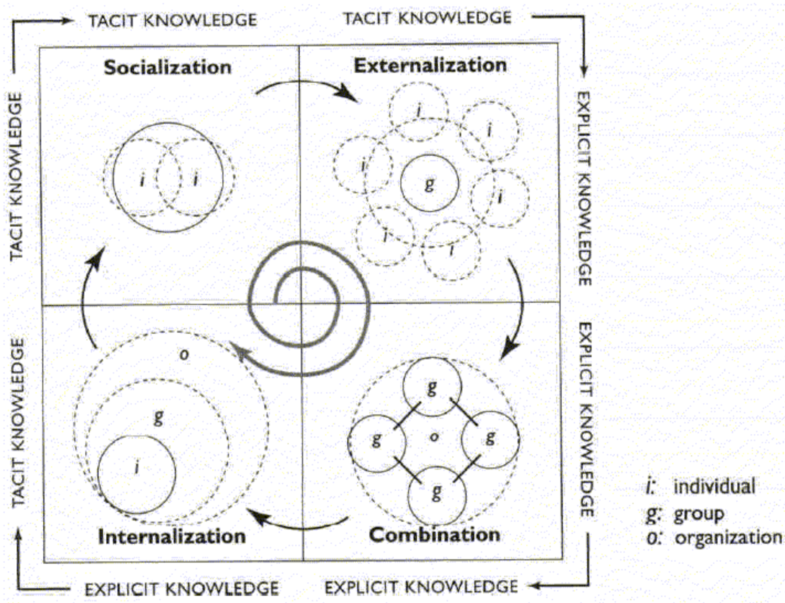


Figure 3. The SECI model (after Nonaka and Konno 1998).

Unlocking Knowledge

Knowledge elicitation is conducted in a workshop setting. Workshops are held with each stakeholder group separately at first. The purpose of the workshops is the build influence diagrams or knowledge maps. This is done in the context of a land condition management objective (such as 3P pastures). The following briefly describes the outcomes of a grazier workshop as an example:

Step 1: Workshop participants are asks to comment on a list of proposed land condition management objectives (3P pastures, ground cover, weeds and timber thickening). Do they think that achieving these objectives is important? What other objectives do they think are important and are these more or less important than the proposed objectives? Once the objectives are agreed, one is selected and the workshop participants are asked to describe ways in which they think this objective can be achieved. The management interventions mentioned are listed above the objective. This starts the knowledge mapping processes.

Step 2: Workshop participants are asked to explain why they think each management intervention will work. The reasons are captured and added to the diagram. These reasons are the effects or outcomes of the management interventions. Then workshop participants are asked if there are any other factors that control these outcomes. These controlling factors are added to the diagram. The last step is to ask the workshop participants what is required to implement the management interventions. These are added and the diagram completed (Figure 4).

Modelling, Representing and Combining Knowledge

Once the workshop process has been completed with each group, Bayesian Belief Networks (BBNs) are used to combine, model and represent the knowledge gathered. BBNs have been used in participatory systems analysis in a number of other resource management situations (Batchelor and Cain 1999; Cain *et al.* 1999; Cain 2001; Sadoddin *et al.* 2003). Essentially they are:

- A set of nodes (factors or variables) representing management system variables, each with a set of mutually exclusive states
- A set of links representing causal relationships between nodes
- A set of probabilities, one for each node, specifying the chance that a node will be in a particular state given the state of things that influence it

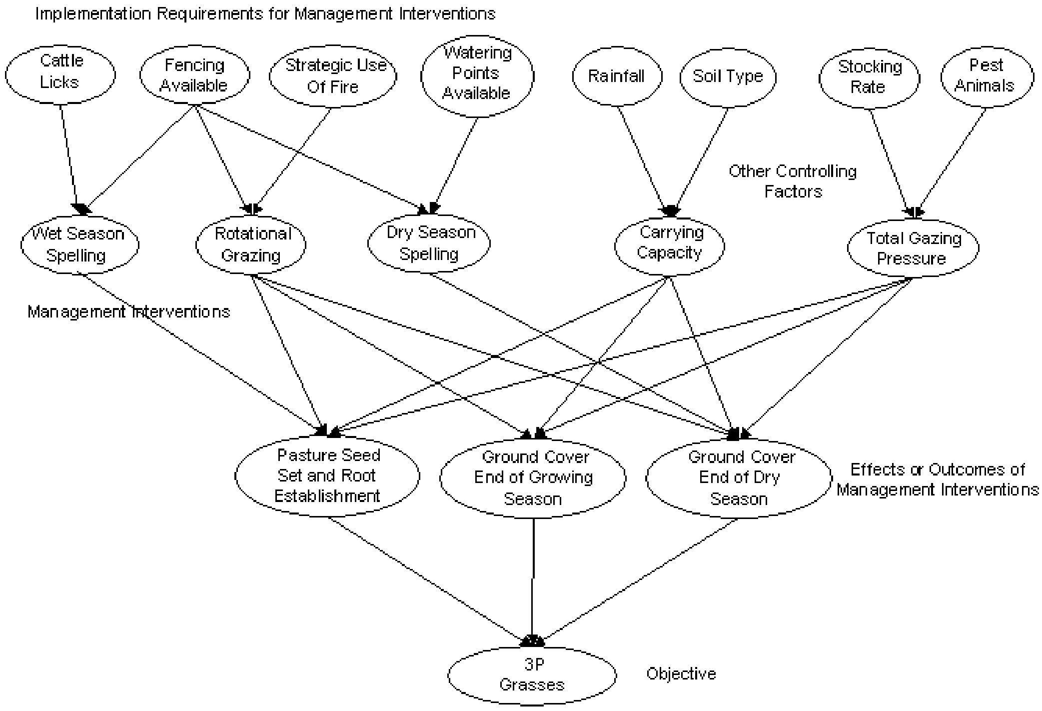


Figure 4. Influence diagram or knowledge map for 3P grasses.

Figure 5 is a BBN developed for pasture condition using the knowledge of a group of scientists (pasture condition is defined here by the quantity of grass and the composition of 3P grasses). Note that each node in the network has a set of states (eg. Low, Average or High). Some nodes have parents (eg. Fire Intensity has the parents Fuel load and Time of Fire) and some node have children (eg. Fire Intensity is the child of Fuel Load and Time of Fire).

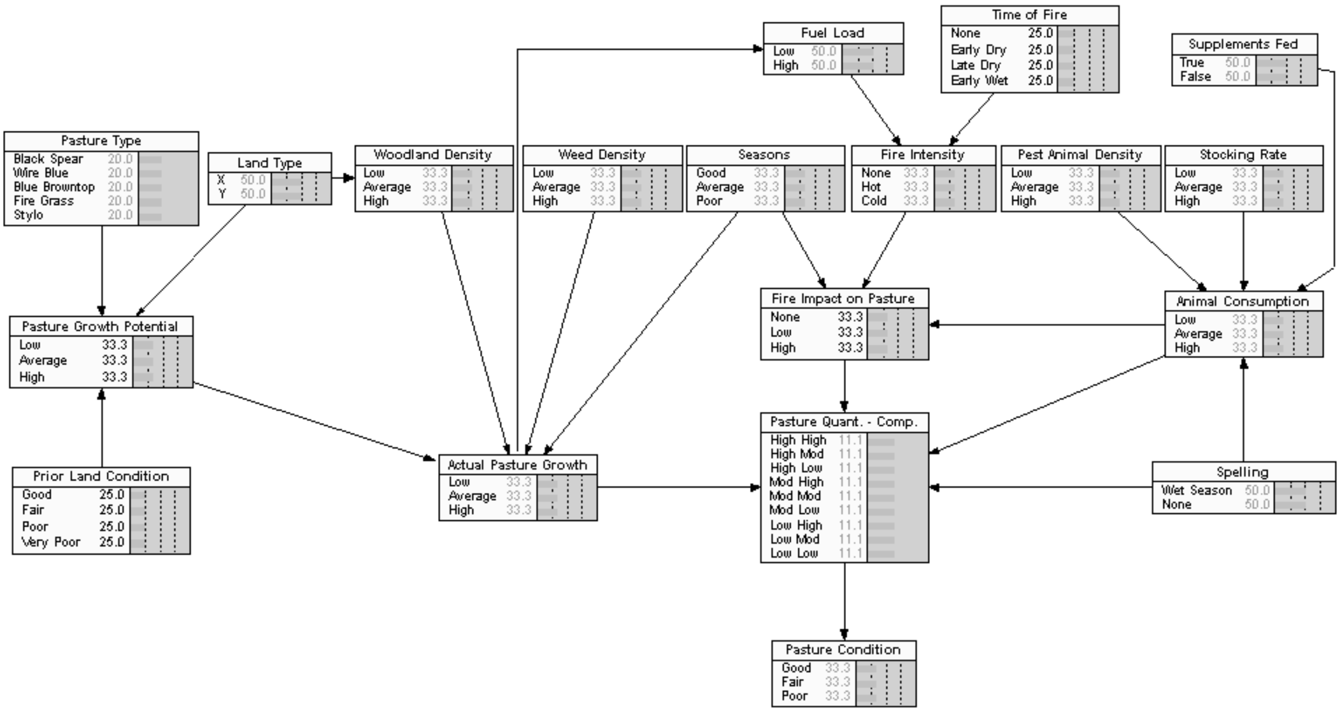


Figure 5. Bayesian Belief Network based on scientists' knowledge of pasture condition.

The knowledge combination process involves combining the BBNs developed for each stakeholder group. This approach has also been used by Cain (2001) to develop water management strategies in a mutli-stakeholder environment. Knowledge combination is carried out through identifying areas in common and areas of difference between the BBNs of different groups.. The areas of difference may be:

- Resource management objectives
- Management interventions
- Effects or outcomes that management interventions have
- Additional controlling factors
- Implementation requirements for management interventions

Areas of differences are discussed with all groups in a joint workshop or discussion forum. Emphasis is on checking with the groups that any differences are not just a consequence of expressing the same idea in different ways. If the differences are real, then each group has a chance to explain their point of view to the others. A compromise or common view may be reached; otherwise more than one view has to be tested in the making sense phase below.

The use of BBNs has been found a most effective approach for modeling and combining knowledge:

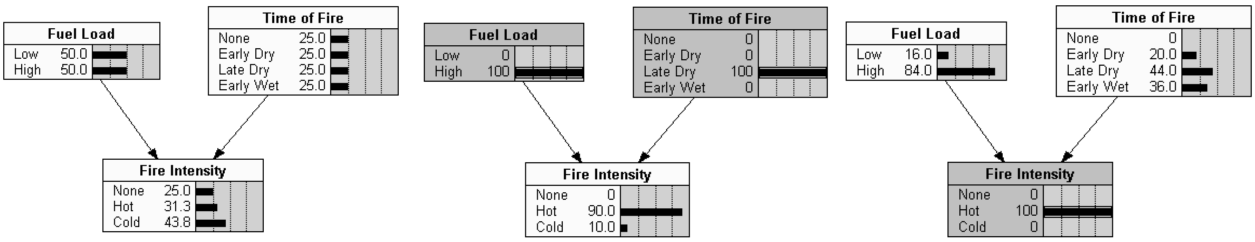
- Uncertainty in knowledge can be expressed explicitly using probabilistic relationships
- Relationships between qualitative and quantitative variables can be easily handled
- The graphical nature of BBNs facilitates communication of between different stakeholder groups
- They can be easily updated as new knowledge comes to hand (nodes added or removed and links changed)

Making Sense of Existing Knowledge

Making sense of existing knowledge involves demonstrating the behaviour of a working BBN model to the stakeholder groups involved. To do this, the model must be populated with probabilities. Each child node in a BBN stores conditional probabilities, that is, the chance that the node will be in each of its states given the states of its parents. For example, the kind of question that will be posed to the stakeholders in Figure 6 would be: What are the chances that *Fire Intensity* will be hot or cold, when *Fuel Load* is high and time of fire is in the *Late Dry Season*? These probabilities can come from a mixture of sources:

- Data or observation (such as monitoring records of *land owners, extension officers, or scientists*)
- Monte Carlo analysis using simulation models (such as a pasture growth model developed by *scientists*)
- Estimates from local people, landowners, extension officers, scientists, policy makers, etc.

Once populated with probabilities, model behaviour is demonstrated to stakeholder groups by a conducting sensitivity analysis. This is done in two ways – by using the BBN in predictive and diagnostic mode. Figure 6 shows each mode in operation. The BBN in Figure 6a shows the chance of a hot or cold fire given a high *Fuel Load* and a *Late Dry Season* fire – predictive mode. The BBN in Figure 6b shows that in order to get a hot fire, *Fuel Load* is most likely to be high and *Time of Fire* is most likely to be during the *Late Dry Season* – diagnostic mode.



(a) (b) (c)

Figure 6. A BBN (a) without a scenario inserted, (b) used in predictive mode, (c) used in diagnostic mode.

If model behaviour does not make sense to the stakeholder groups, the following questions need to be answered:

- Are all significant variables included in the model?
- Do the links between variables make sense?
- Do the states that each variable can take make sense?
- Do the probabilities in the model make sense?

Answering these questions will reveal knowledge gaps or unlock new knowledge about the NRM system.

Building New Knowledge

The making sense process identifies management strategies that are most likely to achieve NRM objectives based on current knowledge. These management strategies are then placed within an adaptive management cycle (Figure 7). In this cycle, management strategies are implemented, the NRM system monitored and the monitoring results used to review the success of the management strategies. BBN models can assist this adaptive management process. They provide a guide to monitoring by outlining the key variables of the NRM system. By monitoring these variables, the monitoring record can be used to update probabilities in the BBN model. The updated model can then be used to review the success of the original management strategies. Over time, this leads to learning (and surprise learning) through the testing of knowledge about the NRM system. This represents a knowledge-building process.

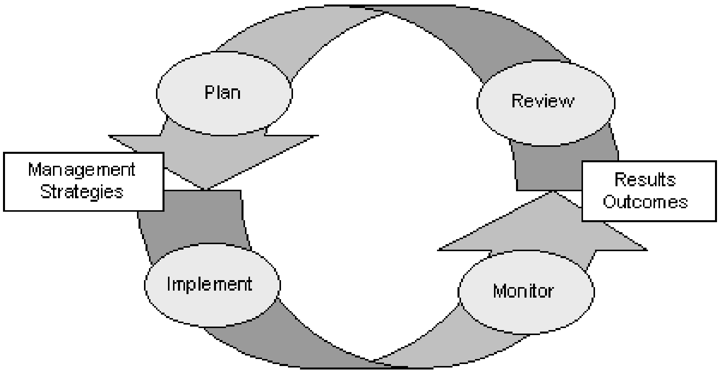


Figure 7. Adaptive management cycle (after Bosch *et al.* 2003)

Conclusions

This paper describes some simple processes and tools for unlocking, modeling, combining and using the disparate knowledge held by stakeholder groups to develop natural resource management (NRM) strategies, and then testing those strategies in an adaptive management environment. Knowledge, particularly non-scientific knowledge, is often under-utilised in NRM strategy development. The tools being developed through this Knowledge Building Project help to integrate different forms of knowledge so that NRM strategies are based on a range of existing knowledge. This further facilitates the adoption and implementation of NRM strategies by local resource managers because they are formulated using their understanding.

Acknowledgements

The authors would like to acknowledge the CRC for Tropical Savannas Management for their financial support.

References

Batchelor, C. and Cain, J. (1999). Application of belief networks to water management studies. *Agricultural Water Management* 40, 51-57.

Bosch, O.J.H., Ross, A.H. and Beeton, R.J.S. (2003) Integrating science and management through collaborative learning and better information management. *Systems Research and Behavioral Science* 20, 107-118.

Bryceson, K. (2003). The KID triangle. In Managerial Decision Support Systems, Course Notes. University of Queensland, Gatton Australia.

Cain, J., Batchelor, C. and Waughray, D. (1999). Belief Networks: A framework for the participatory development of natural resource management strategies. *Environment, Development and Sustainability* 1, 123-133.

Cain, J. (2001). Planning improvements in natural resources management: Guidelines for using Bayesian networks to support the planning and management of development programs in the water sector and beyond. Centre for Ecology and Hydrology, Wallingford UK.

Davenport, T. (1997). Information ecology: mastering the information and knowledge environment. Oxford University Press, Oxford UK.

Mackinson, S. and Nottestad, L. (1998). Combining local and scientific knowledge. *Reviews in Fish Biology and Fisheries* 8, 481-490.

Nonaka, I. and Konno, N (1998). The Concept of 'Ba': Building a foundation for knowledge creation. *California Management Review* 40(3), 40-54.

Sadoddin, A., Letcher, R.A. and Jakeman, A.J. (2003). A Bayesian decision network approach for salinity management in the little river catchment, NSW. *Proceedings MODSIM 2003: Integrative Modelling of Biophysical, Social and Economic Systems for Resource Management Solutions.* p953-958. Townsville, Australia.